



Aerocapture Technology Development for Planetary Science - Update

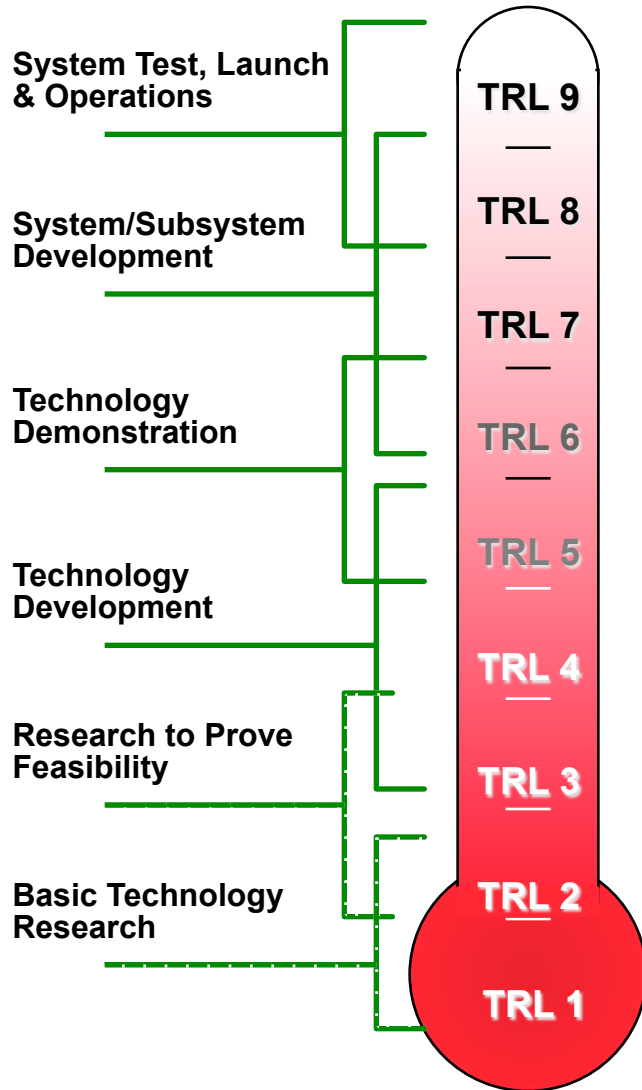
*Michelle M. Munk
In-Space Propulsion Technology Program
NASA Marshall Space Flight Center*

*4th International Planetary Probe Workshop
June 29, 2006*

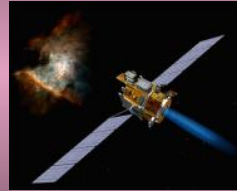


- **Introduction**
 - In-Space Propulsion Technology (ISPT) Program Background
 - Aerocapture Overview and Benefits
- **Major Accomplishments and Relevance to Future Missions**
 - Highlight 1: Aeroshell Sensors
 - Highlight 2: Advanced TPS Testing
 - Highlight 3: Efficient Hot Structures
- **Recent Study Results**
- **Next Steps: Flight Validation and Infusion**

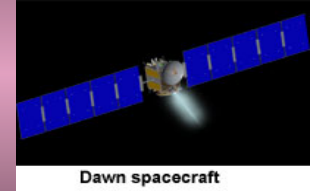
ISPT Program Focuses On Mid-TRL Propulsion System Development & Integration



Flight Validation and Mission Implementation: (Solar Electric Propulsion Example)



NSTAR (Deep Space 1)



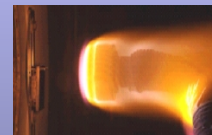
Dawn (In Development)

In-Space Propulsion Technologies

Advanced Chemical Propulsion



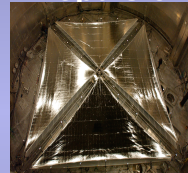
Aerocapture



Solar Electric Propulsion



Solar Sail Propulsion

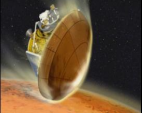


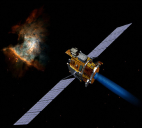



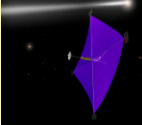




Research (not part of ISPT)



In-Space Propulsion Technology Program Priorities 2002 to 2006



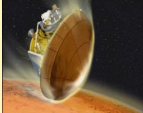

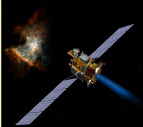
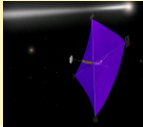
High Priority	Medium Priority	Low Priority	High Payoff High Risk
Aerocapture 	Adv. Chem. 		1 g/m2 S. Sails 
Next Gen. Ion 	SEP <50 kW 	Solar Thermal 	MXER Tethers 
Solar Sails 	SEP Hall 100kW 		Plasma Sails 

ISPT Priorities 2002

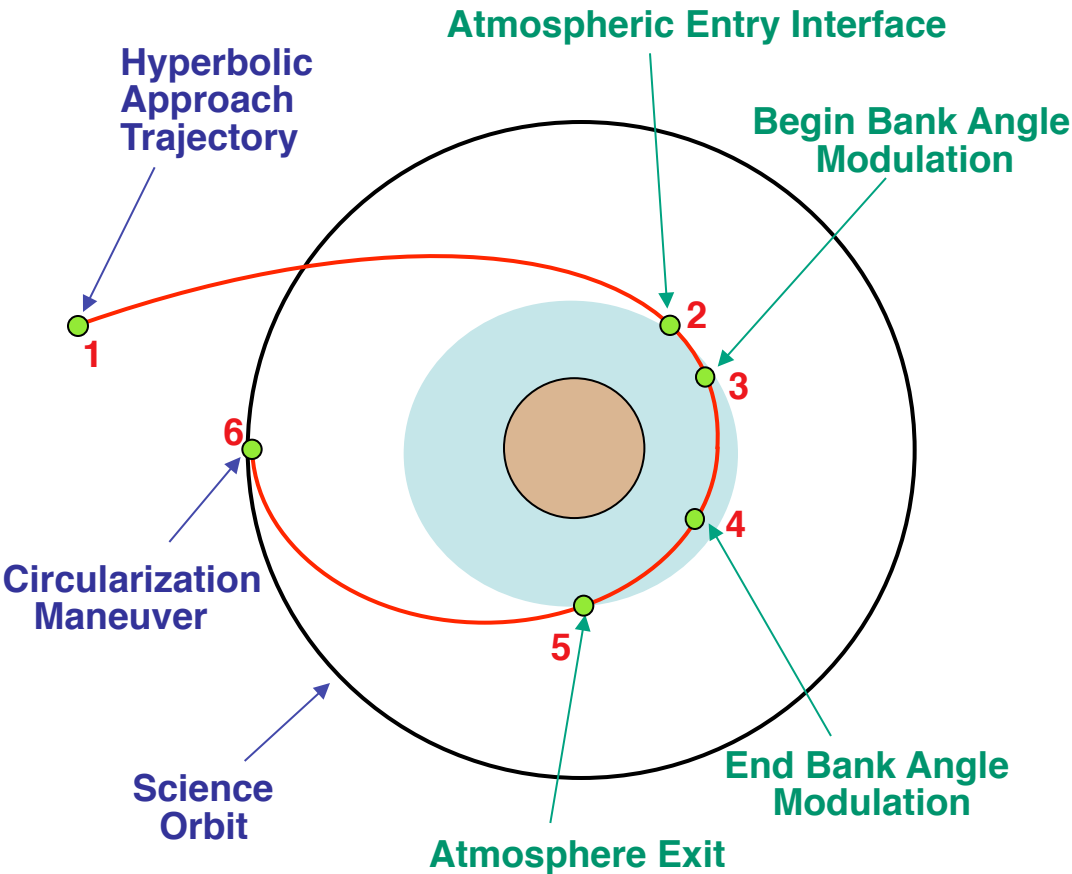
- Flagship mission propulsion needs
 - Outer planet destinations
 - Agency-wide needs
- Low level technology push

ISPT Priorities 2006

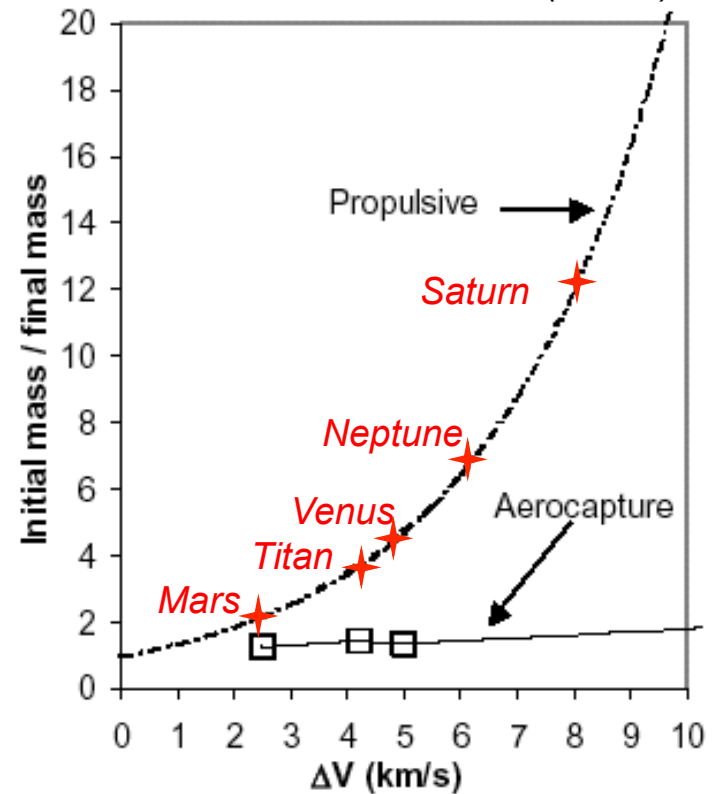
- Focus on near-term deliverables for SMD
- GOALS:
 - enhance/enable science missions
 - lower cost
 - reduce risk to end user
- Technologies linked to SMD mission pull

High Priority	Medium Priority	Low Priority	High Payoff High Risk
Aerocapture 	Adv. Chem. 		
Solar Electric 			
Solar Sails 			

Aerocapture Overview

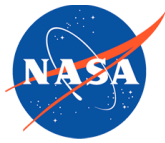


Capture Propellant Mass Fraction
(The Rocket Equation)
Compared to
Aeroshell Mass Fraction (Linear)



Aerocapture makes use of a planetary body's atmosphere to slow a vehicle and place it into orbit using very little propellant.

Aerocapture Enables Payload Increases



Mission	Orbit Insertion ΔV, km/s	Best A/C Mass, kg	Best non-A/C Mass, kg	A/C % Increase
Venus - 300 km circ	4.6	5078	2834	79
Venus - 8500 x 300 km	3.3	5078	3542	43
Mars - 300 km circ	2.4	5232	4556	15
Mars - ~1 Sol ellipse	1.2	5232	4983	5
Jupiter - 2000 km circ	17.0	2262	<0	Infinite
Jupiter - Callisto ellipse	1.4	2262	4628	-51
Saturn - 120,000 km circ	8.0	494	<0	Infinite
Titan - 1700 km circ	4.4	2630	691	280
Uranus - Titania ellipse	4.5	1966	618	218
Neptune - Triton ellipse	6.0	1680	180	832

Aerocapture Project Approach



- **OBJECTIVE:** Raise aerocapture propulsion to TRL 6 through the development of subsystems, tools, and system level validation and verification.
- **Identify and mitigate risk factors for Aerocapture infusion into science missions**
- **Technical discipline areas:**
 - Atmospheric modeling
 - Aerodynamics
 - GN&C
 - Aerothermodynamics
 - Structures and TPS
 - System integration
- **Includes nearly all development cycle tasks**
 - concept studies
 - model development
 - detailed analysis
 - manufacture
 - test
 - model validation

Aerocapture Technology

Specific Architectures



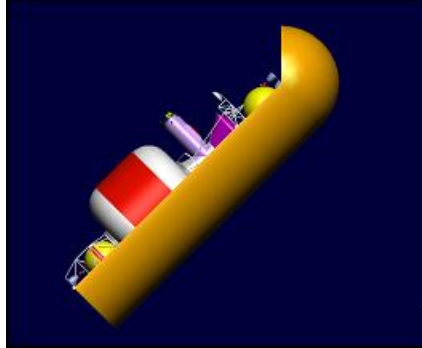
Higher TRL

Blunt Body Designs



- Moderate to high maturity for small bodies; low to moderate maturity for other planets
- Provides modest tolerance for nav and atmospheric uncertainties

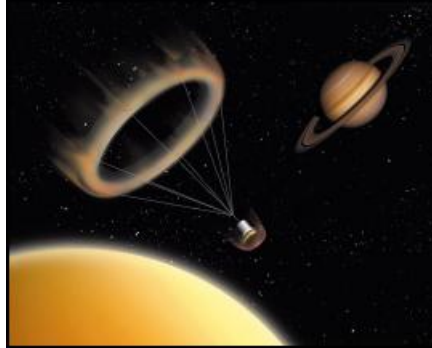
Slender Body Designs



- Low to moderate maturity
- Provides increased tolerance for nav and atmos. uncertainties
- Design originally for human missions to Mars. Preliminary studies indicate that Slender Body Designs may be required for Neptune.
- Provides increased volume and improved packaging advantages for larger spacecraft.

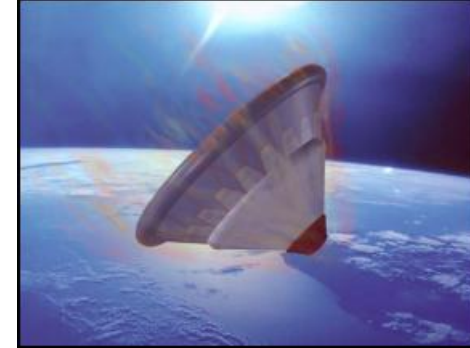
Lower TRL

Trailing Ballutes



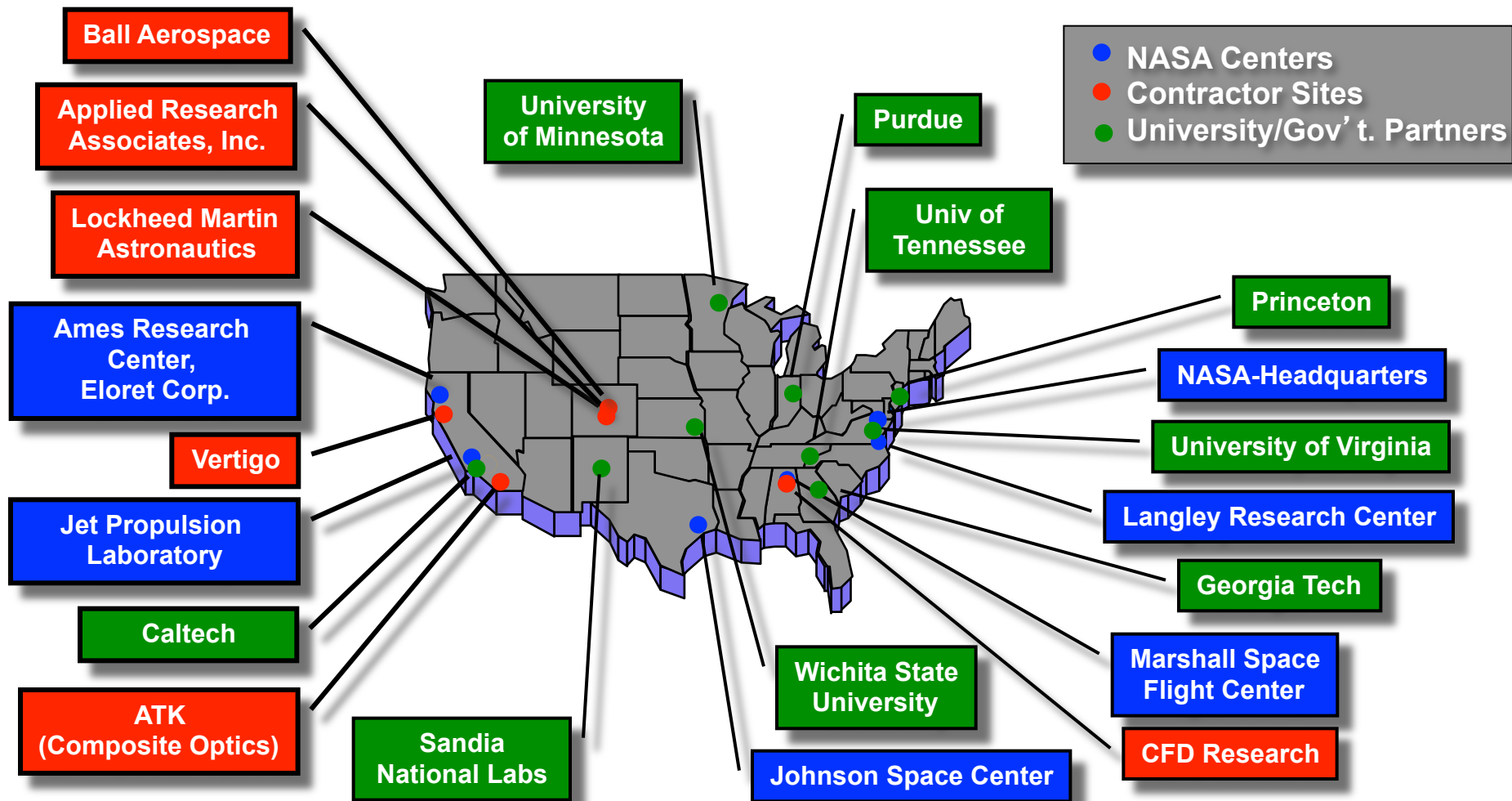
- Low maturity
- Applicable to all size and shape payloads
- May have performance advantages over Blunt Body, such as not having the payload enclosed during interplanetary cruise

Attached Ballutes



- Low to moderate maturity for Earth and Mars
- Developed and launched in 1996 by Soviet Union as part of Mars penetrator mission. Launch vehicle failure.
- Investigating feasibility of using aerodynamic lift for precision trajectory control
- Has potential volume and packaging advantage for larger spacecraft

ISPT Aerocapture Team



The ISPT Aerocapture Team is distributed across the United States.

Current Competed Aerocapture Tasks

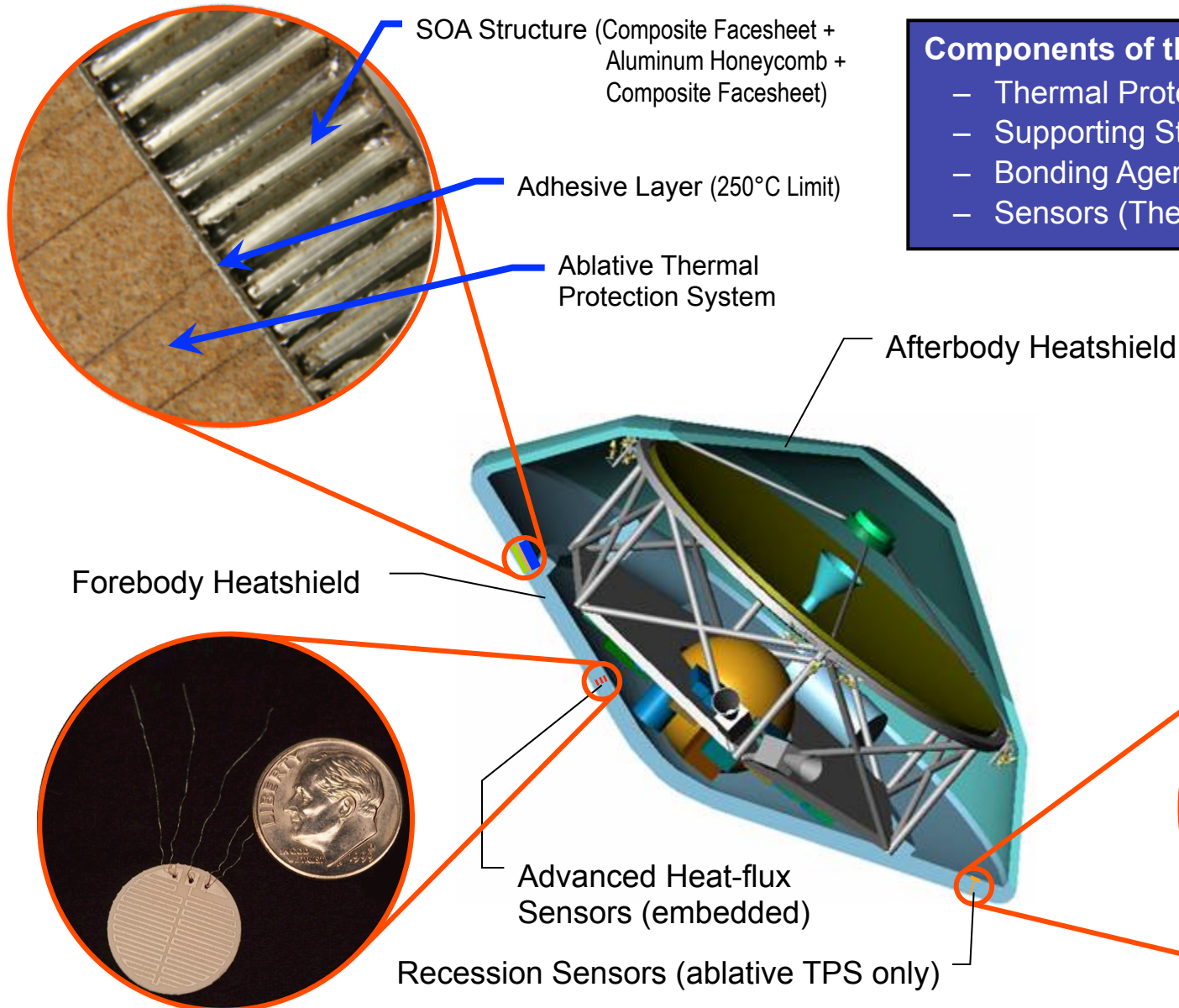


	Title	Lead Organization	Major Products
Rigid Aeroshell-Related Tasks	1) Aeroshell Development for Aerocapture	NASA-ARC	<ul style="list-style-type: none"> Fully characterized TPS materials and response models for Titan TPS concepts and heating predictions for other small-body destinations
	2) Microsensor & Instrumentation Technology for Aerocapture	NASA-ARC	<ul style="list-style-type: none"> Heat flux and recession microsensors ready for use in Titan and other small body aerocapture environments Integrated aeroshell sensor suite
	3) Advanced Ablator Families for Aero-assist Missions	Applied Research Associates	<ul style="list-style-type: none"> Fully tested and characterized ablator options utilizing low-cost manufacturing techniques Tests of integrated low-mass structures and ablators
	4) High-Temp Structures for Reduced Aeroshell Mass	NASA-LaRC	<ul style="list-style-type: none"> Reduced mass aeroshell composite structures, tested for aerocapture environment Validation of ablator/structure interface using high-temp adhesives 2 (1-meter) rigid aeroshell test articles, thermally tested and validated against FEM
	5) Aerocapture Technologies	Lockheed Martin Space Systems	<ul style="list-style-type: none"> Development of 2 structural/TPS concepts using traditional and advanced materials and manufacturing techniques (1 SLA, 1 C-C) 1 (2-meter) rigid aeroshell article, mechanically tested to Titan aerocapture loads
Inflatable-Related Tasks	6) Technology Development of Ballute Aerocapture	Ball Aerospace	<ul style="list-style-type: none"> Trailing ballute system concepts for Titan and Neptune Ground test verification of ballute manufacturing and packaging
	7) Clamped Afterbody Decelerator (Cycle 2)	Ball Aerospace	<ul style="list-style-type: none"> Systems design, technology challenges of inflatable afterbody ballute deceleration system Builds on previous work with Gossamer Program
	8) Inflatable Forebody Aerocapture Concepts (Cycle 2)	Lockheed Martin Space Systems	<ul style="list-style-type: none"> Systems design, technology challenges of inflatable aeroshell system Builds on previous work for Mars Program

The Rigid Aeroshell System

Components of the Rigid Aeroshell

- Thermal Protection System
- Supporting Structure
- Bonding Agent/Adhesive
- Sensors (Thermal, Recession)

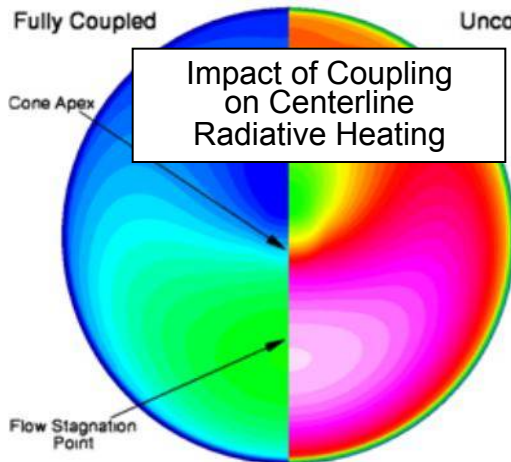


TASK 1:

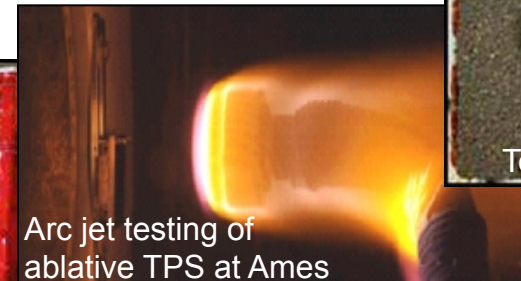
Aeroshell Development for Aerocapture



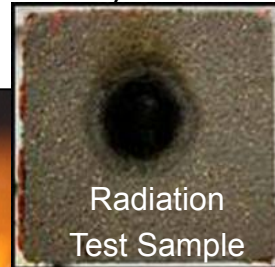
- **Summary** - NASA ARC is focusing on reducing uncertainties in aeroshell design for a Titan aerocapture mission. This involves evaluating the aerothermal environment & candidate TPS materials.
- **Accomplishments:**
 - ❑ Completed arc jet screening tests in a nitrogen atmosphere of candidate TPS materials for Titan aerocapture
 - ❑ Completed testing candidate Titan TPS materials in ISPT-funded Radiative Lamp Facility
 - ❑ Demonstrated that coupling the convective and radiative heating solutions reduces the radiant heating in comparison to uncoupled solutions
 - ❑ Completed tests in the EAST shock tunnel to measure shock layer radiation in a simulated Titan atmosphere at relevant conditions
 - ❑ Completed tests in the Caltech T5 facility to measure turbulent convective heating in a simulated Titan atmosphere at relevant conditions
 - ❑ Devised an innovative Monte Carlo approach to aerothermal uncertainty analysis (many references)
- **Plans:**
 - ❑ Continue aerothermal modeling



ISPT-Funded Radiant Lamp Test Facility at ARC



Arc jet testing of ablative TPS at Ames



Radiation Test Sample

Contact: Bernie Laub
blaub@mail.arc.nasa.gov
M/S 234-1 NASA ARC
Moffet Field, CA 94035
650.604.5017

TASK 2:

Microsensor & Instrumentation Technology for Aerocapture

➤ **Summary** - ARC is developing heat flux and recession sensors for rigid aeroshells. Data from these sensors will be used to optimize design of future aeroshells for aerocapture and direct entry missions.

➤ **Accomplishments:**

- ❑ Initial sensor design and fabrication is complete
- ❑ Laboratory arcjet is complete and operational
- ❑ Sensors have been integrated into ablative TPS materials
- ❑ Arcjet testing of heat flux and recession sensors is underway



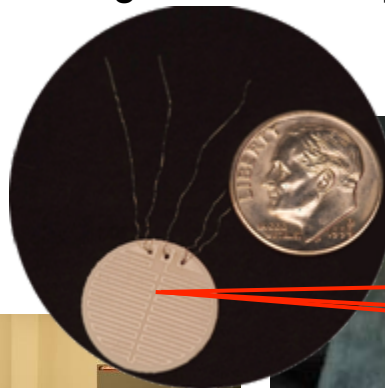
ARC recession sensors integrated into ARA ablator for initial arcjet screening

➤ **Plans:**

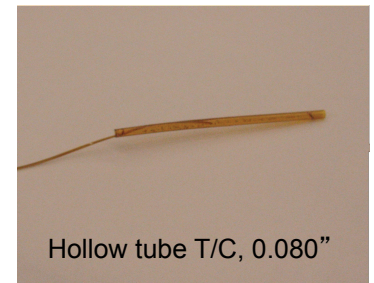
- ❑ Continue full-scale thermal testing on integrated TPS/sensor samples to perfect sensor design and develop calibration curves for each TPS material



The ARC lab and sensor fabrication equipment is a new capability



The ARC heat flux sensor has been tested to relevant heating levels in well-characterized TPS



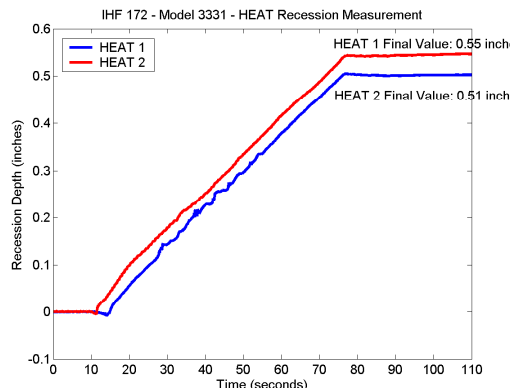
Contact: Ed Martinez
ed.martinez@nasa.gov
 Ames Research Center
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 Moffett Field, CA 94035
 650.604.2544

Recent Aeroshell Sensor Accomplishments

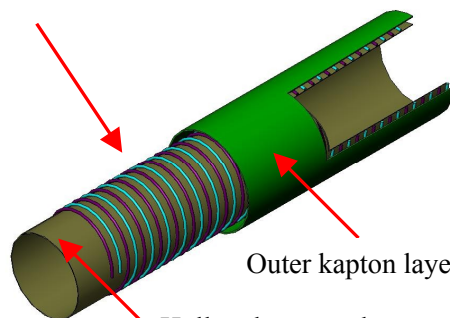
➤ In May, 2006, highly-instrumented samples of two lightweight ablators were arcjet-tested at over 250 W/cm^2

➤ Instruments included:

- ☐ Thermocouple stack in plug
- ☐ Hollow tube thermocouple implementation
- ☐ Recession sensors (traditional ARAD, and new HEAT)
- ☐ Pressure ports/transducers

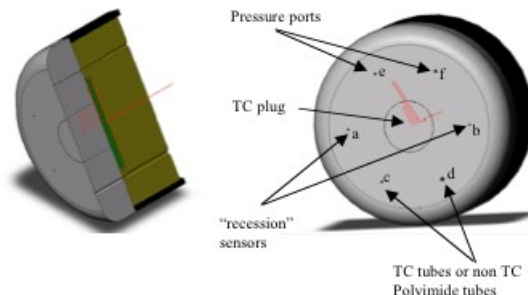


Wound resistive wire



Outer kapton layer (tube or coating)

Hollow kapton tube



Model	Ablator	Insulator	"recession" sensors	Pressure Port type
3323	SRAM 20	cork	HEAT	SS 0.0625
3329	SRAM 20	cork	ARAD	Hole 0.050
3331	SRAM 20	cork	HEAT	SS 0.042
3332	SRAM 20	cork	ARAD	Hole 0.035
3351	SRAM 20	cork	HEAT	SS 0.032
3352	SRAM 20	cork	ARAD	Hole 0.025
S4F-1	SLA-561V	FRCI 12	HEAT	SS 0.0625
S4F-2	SLA-561V	FRCI 12	HEAT/ARAD	Hole 0.050



Aeroshell Sensor Summary

- **Demonstrated application of Temperature, Pressure, Heat Flux, and Recession measurements in ablative TPS at relevant Titan and Mars aerocapture conditions**
 - Heat flux, heat loads, pressures, temperatures, recession rates
 - Forebody and aftshell arc jet testing
- **Demonstrated in several other materials and applications**
 - PICA (ARC), PhenCarb (ARA), SRAM (ARA), Teflon in arc jet testing
 - Applied thermal sensors to balloon drop test - June 06
 - Applied recession sensor to sounding rocket test - Sep 06
- **Additional test opportunities in July and August will refine implementations**

Instrumenting entry aeroshells is vital to increasing our understanding of the entry environment and reducing risk on future missions.

TASK 3:

Advanced Ablator Families for Aeroassist Missions



➤ **Summary** - ARA is developing and testing candidate ablator materials for aerocapture TPS. Test samples are formulated at the ARA facility in Denver & tested at various facilities that simulate the aerocapture environment.

➤ **Accomplishments:**

- ❑ Completed convective heating tests at the Ames Research Center Arcjet Facility
- ❑ Completed radiative screening of TPS coupons at Sandia Solar Tower
- ❑ Completed proof-of-concept manufacturing of large-cell honeycomb and honeycomb-packed TPS
- ❑ Updated TPS thermal response models

➤ **Plans:**

- ❑ Return to Sandia Solar Tower to conduct TPS/Structure panel testing
- ❑ Thermally test two 1-meter aeroshells at Sandia Solar Tower
- ❑ Update TPS/system thermal response models



Ablator arcjet coupons, post test

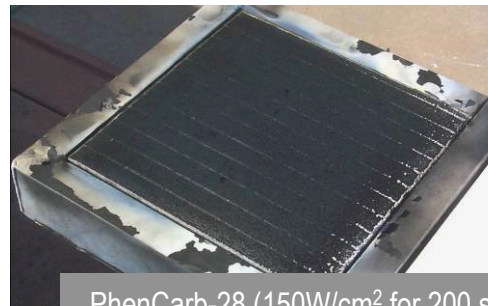


Solar tower test of ablator panel



Solar tower test of ablator coupons

Panel test video



PhenCarb-28 (150W/cm² for 200 sec)



Ablator solar tower coupon, post test

Contact: Bill Congdon
bcongdon@msn.com
ARA, Ablatives Laboratory
14824 E. Hinsdale Ave.
Unit C
Centennial, CO 80121
303.699.7737

TASK 4:

High-Temp Structures for Reduced Aeroshell Mass



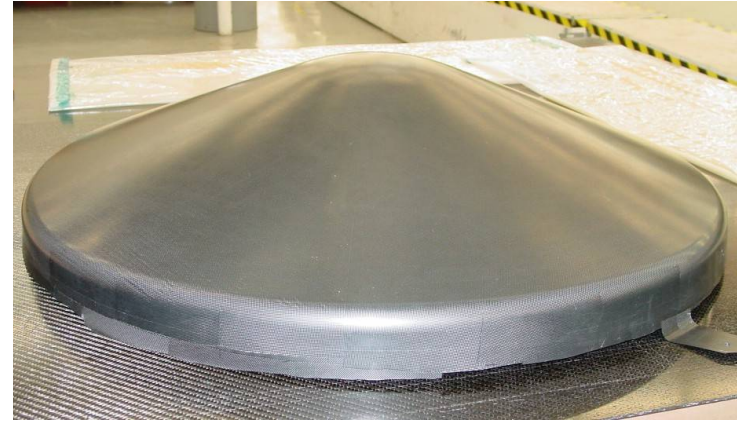
➤ **Summary** – LaRC and partner ATK are selecting candidate adhesives for attaching the TPS to the structure of the aerocapture heat shield. They are also investigating new high-temperature resins and core materials to be used to manufacture the structure.

➤ **Accomplishments:**

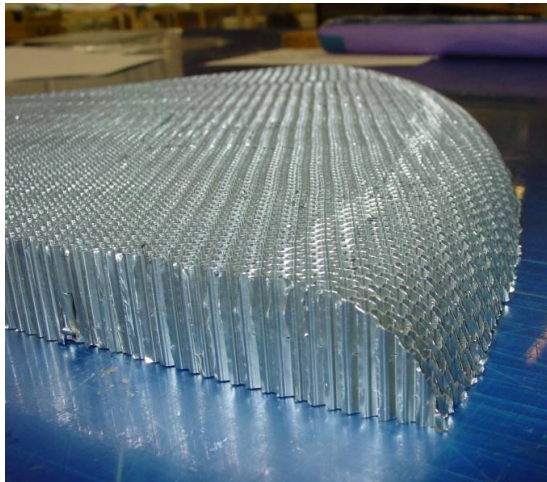
- ❑ ASTM laboratory tests conducted on several adhesives
- ❑ Completed composite materials testing (new resins and core)
- ❑ CTE and bond testing of ablator materials complete
- ❑ FEM of aeroshell system complete

➤ **Plans:**

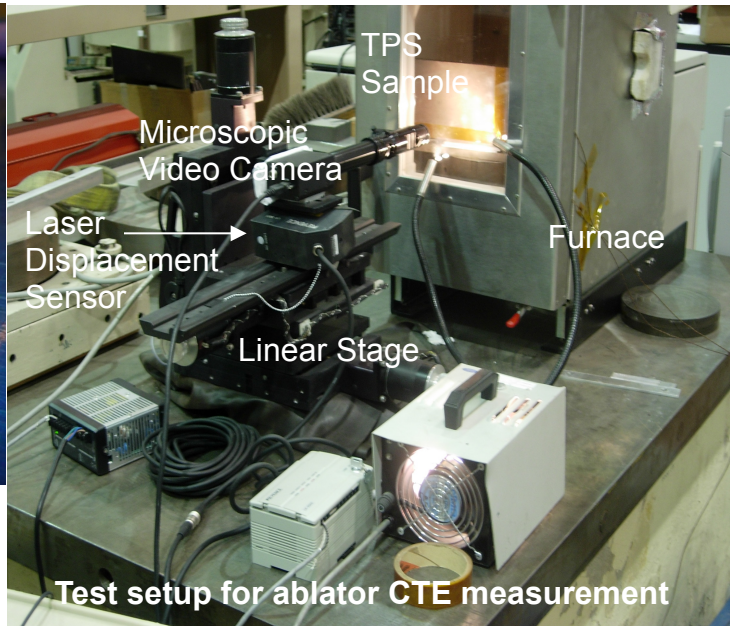
- ❑ Complete fabrication of two 1-meter aeroshells
- ❑ Validate predictive system models with test data



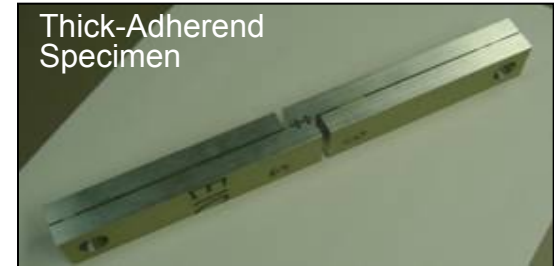
Completed 1m aeroshell
Al-honeycomb structure outer skin



Aluminum flex core machined
for insertion into outer skin



Test setup for ablator CTE measurement



Contact: Tim Collins
t.j.collins@larc.nasa.gov
M/S 190 NASA LaRC
Hampton, VA 23861
757.864.3113

TASK 5:

Aerocapture Technologies



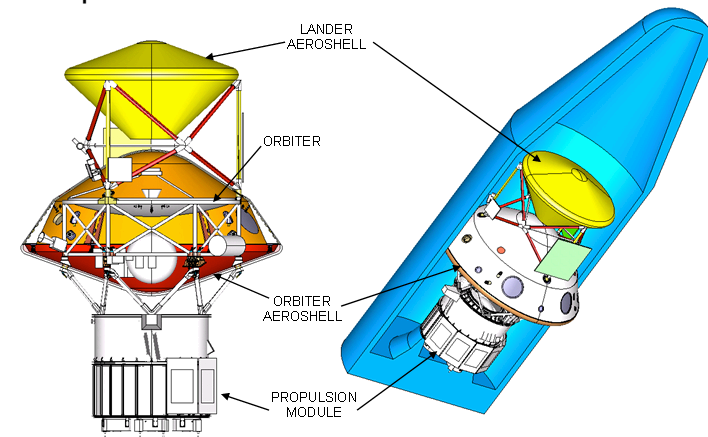
➤ **Summary** - Lockheed Martin Astronautics is developing composite “warm” & “hot” structure materials for rigid aeroshells. The “warm” structure is capable of higher-temperature performance, requiring less TPS than traditional aluminum structure. The “hot” structure is able to handle the intense heat of aerocapture or direct entry without the use of TPS, and has much higher temperature capabilities than traditional ablative TPS.

➤ **Accomplishments:**

- ❑ Conceptual design of a rigid aeroshell for Titan aerocapture complete. Lander, propulsion module, backshell, and orbiter separation modes have been examined and preliminary designs have been completed.
- ❑ Completed arcjet testing at NASA ARC for traditional TPS and warm structure coupons
- ❑ Completed radiative lamp testing on warm and hot structure coupons
- ❑ Completed mechanical testing on hot structure coupons
- ❑ Completed mechanical testing on 2-meter hot structure article

➤ **Plans:**

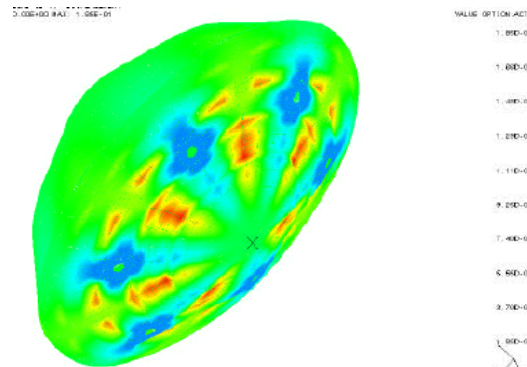
- ❑ Complete arcjet testing of warm and hot structure coupons at NASA ARC
- ❑ Validate thermal and mechanical models with test data



LMA Titan aerocapture design



2m C-C Hot Structure Aeroshell



Aeroshell Displacements (Limit)

Contact: Bill Willcockson
william.h.willcockson@lmco.com

LMA
P.O. Box 179
Denver, CO 80201
303.977.5094

LMSS - Warm Structure System Testing

Levels bound Titan and Mars aerocapture heating rates.	Sample Description	Heat Rate (W/cm ²)	Test Time (sec)	# Samples	Test
	TPS Materials Screening	35	100-200	6	MSL
	TPS Materials Screening	67	50-100	6	MSL
	TPS Materials Screening	78	96-100	2	Titan N2
	Warm Structure	99	92	2	ATA I
	Structural Pass-through Experiment	99	92-100	3	ATA I
	TPS Materials Screening	100	33-67	6	MSL
	Warm Structure	137	80-160	7	ATA III
	SLA-561V with Aluminum Substrate	137	80	1	ATA III
	Alternate SLA / Phenolic Core Experiment	137	80	3	ATA III
	Structural Pass-through Experiment	137	80	1	ATA III
	TPS Materials Screening	163	55	2	Titan N2
	TPS Materials Screening	181	55	2	Titan N2
	Warm Structure	194	60-120	7	ATA III
	SLA-561V with Aluminum Substrate	194	60	1	ATA III
	Alternate SLA / Phenolic Core Experiment	194	60	3	ATA III
	Structural Pass-through Experiment	194	60	1	ATA III
	Warm Structure	206	40-69	4	ATA I
	Structural Pass-through Experiment	206	45	1	ATA I
	TPS Materials Screening	235	25-45	5	MSL
	Warm Structure	281	20-30	4	ATA I
	Warm Structure	308	40-60	6	ATA III
	Alternate SLA / Phenolic Core Experiment	308	40	1	ATA III
	Structural Pass-through Experiment	308	40	1	ATA III
	TPS Materials Screening	358	17-30	6	MSL
	Warm Structure	387	30-60	7	ATA III
	Alternate SLA / Phenolic Core Experiment	387	30	1	ATA III
	Structural Pass-through Experiment	387	30	1	ATA III
	Total Number of Arc Jet Samples			90	



Silica Phenolic Collar at 100 W/cm²



Ames Titan Radiant Lamp



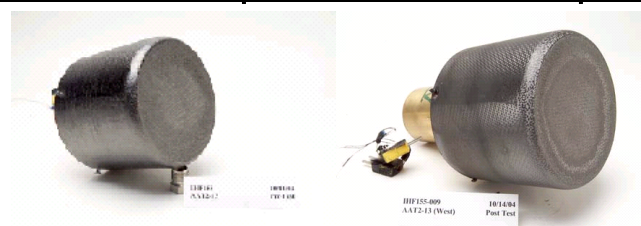
Arc Jet III Passthrough

LMSS - Hot Structure System Testing

	Sample Description	Heat Rate (W/cm ²)	Test Time (sec)	# Samples
Titan, Mars Applications	Standard Hot Structure	137	80	6
	Hot Structure with Advanced Insulation	137	80	2
	Coated Hot Structure	137	80	4
	Collar and Sandwich Experiments	137	80	2
	Standard Hot Structure	194	60	1
	Standard Hot Structure	308	40	5
	Hot Structure with Advanced Insulation	308	40	2
	Coated Hot Structure	308	40	3
	Collar and Sandwich Experiments	308	40	2
	Coated Hot Structure	387	30	1
	Collar and Sandwich Experiments	387	15-20	4
Venus, Earth Applications	Standard Hot Structure	730	18	2
	Hot Structure with Advanced Insulation	730	18	2
	Coated Hot Structure	730	18	1
	Structural Carbon-Carbon Experiment	730	18	2
	Collar and Sandwich Experiments	730	6-10	2
	Standard Hot Structure	913	12	2
	Hot Structure with Advanced Insulation	913	12	1
	Structural Carbon-Carbon Experiment	913	12	1
Total Number of Samples				45



C-C Collared Arc Jet Sample

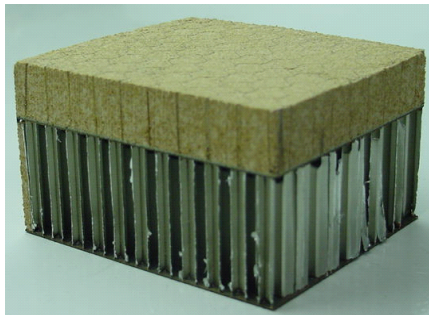


C-C Standard Arc Jet Sample 913 W/cm²

Incremental Changes to Flight-Proven Designs Provide Low-Risk Aeroshell Mass Improvements

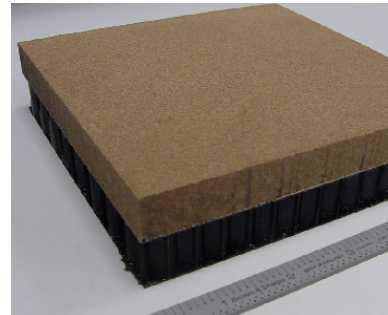


- **Warm Structure System Model - based on MER, MPF, validated with testing**



MER SLA -561V System

Areal Density = 2.07 lb/ft²



Warm Structure SLA-561V System

Areal Density = 1.78 lb/ft²

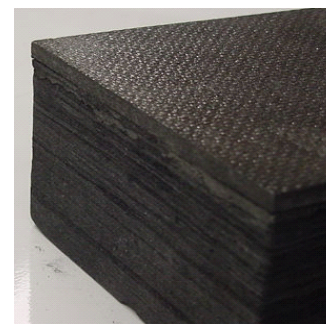
**14%
Improvement**

- **Hot Structure System Model - based on Genesis, validated with testing**
 - Does Not Yet Include Coatings or Newer Versions of MLI-HT
 - Possible System Mass Improvement of **41%+ after arcjet test validation**



Genesis Carbon-Carbon

Areal Density = 3.34 lb/ft²



Hot Structure
C-C/Calcarb

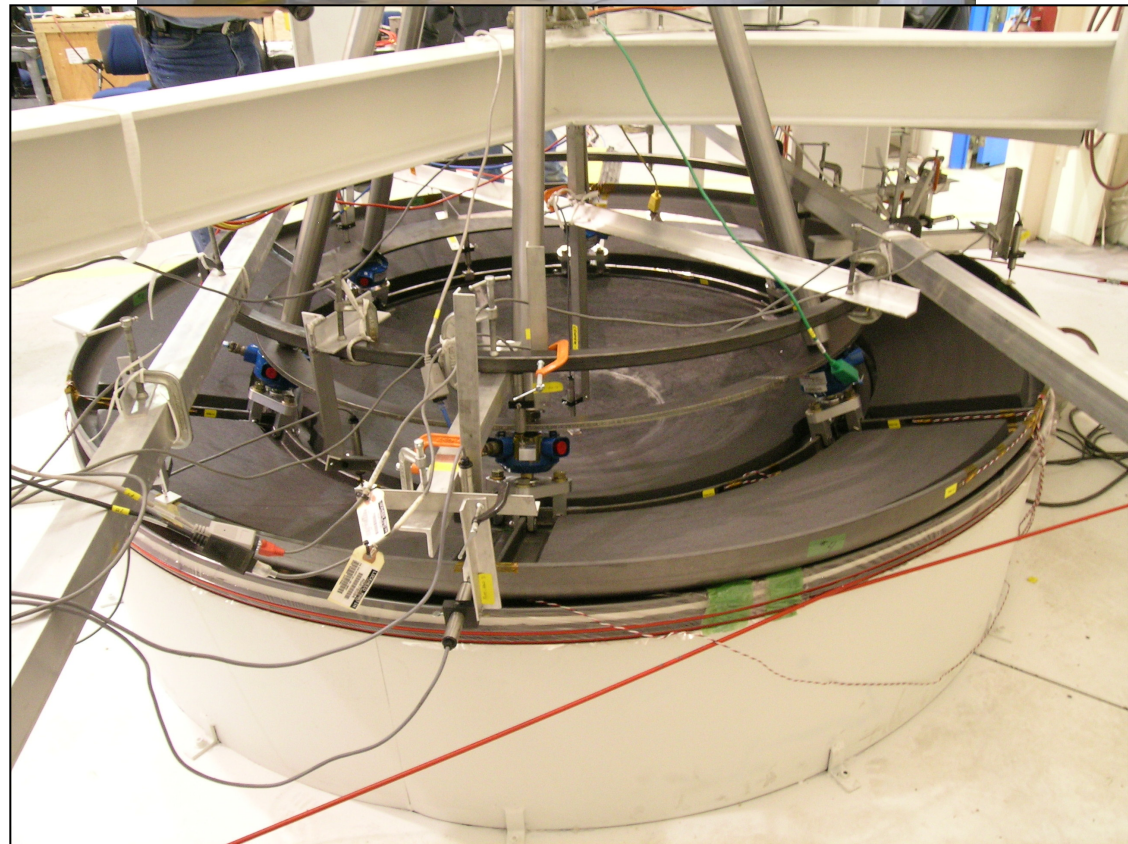
Areal Density = 2.57 lb/ft²

**23%
Improvement**

Carbon-Carbon Large Scale Demonstrator Structural Test Complete!



- Full static load test to acceptance levels successfully completed on May 31, 2006.
- Deflection and strain recorded at several locations, and early results indicate agreement with FEM to within 10%, with the model a bit conservative.
- Visual inspections during the pressure ramp showed no test-induced defects; post-test inspection confirmed.
- C-CAT will conduct detailed NDE.
- FEM will be validated based on these test results and documented in final report early results indicate agreement to within 10%.



TASK 6 and 7: Technology Development of Ballute Aerocapture and Clamped Afterbody Decelerator



➤ **Summary** – Under Cycle 1, Ball Aerospace is performing critical investigation for an aerocapture concept that utilizes a towed inflatable toroid. Trade studies include analysis of aspect ratio for optimal toroidal shape, tether dynamics for optimizing the number of tethers required, separation algorithms to optimize guidance and control, aerothermodynamics and heating for selection of materials and determination of material thickness. Under Cycle 2, Ball is completing system design and identifying technology gaps associated with an inflatable afterbody ballute deceleration system.

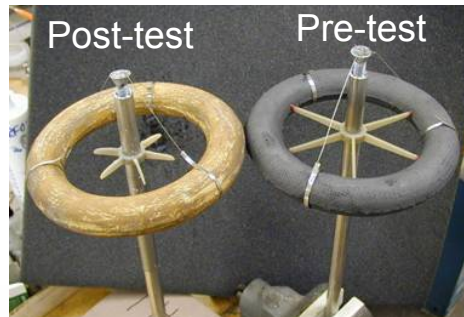
➤ **Accomplishments:**

- ❑ High-temperature and strength testing complete for multiple candidate ballute and tether materials
- ❑ Guidance and control algorithms developed and successfully demonstrated in Monte Carlo simulations
- ❑ Initial system design for Titan complete
- ❑ Preliminary hypersonic validation tests conducted

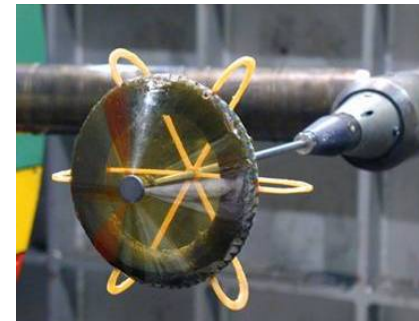
➤ **Plans:**

- ❑ Development of scale inflatable assemblies for test verification
- ❑ Continued material tests and seaming development
- ❑ Develop earth flight validation concept
- ❑ Develop clamped ballute technology

Hypersonic tunnel testing of Trailing and Clamped Ballutes



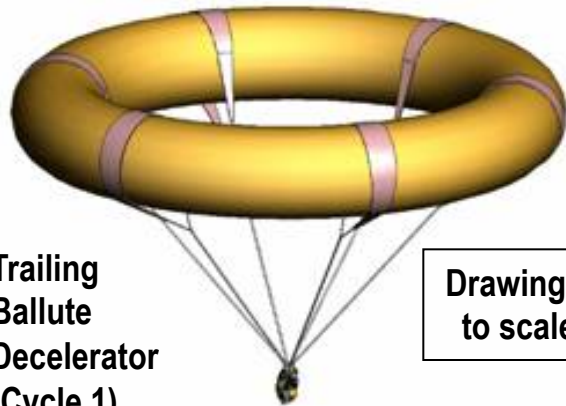
Trailing Ballute Model



Clamped Ballute Model
on Sting Arm



Clamped
Ballute
post-test



Trailing
Ballute
Decelerator
(Cycle 1)

Drawings
to scale



Clamped Ballute
Decelerator (Cycle 2)

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TASK 8:

Inflatable Forebody Aerocapture Concepts



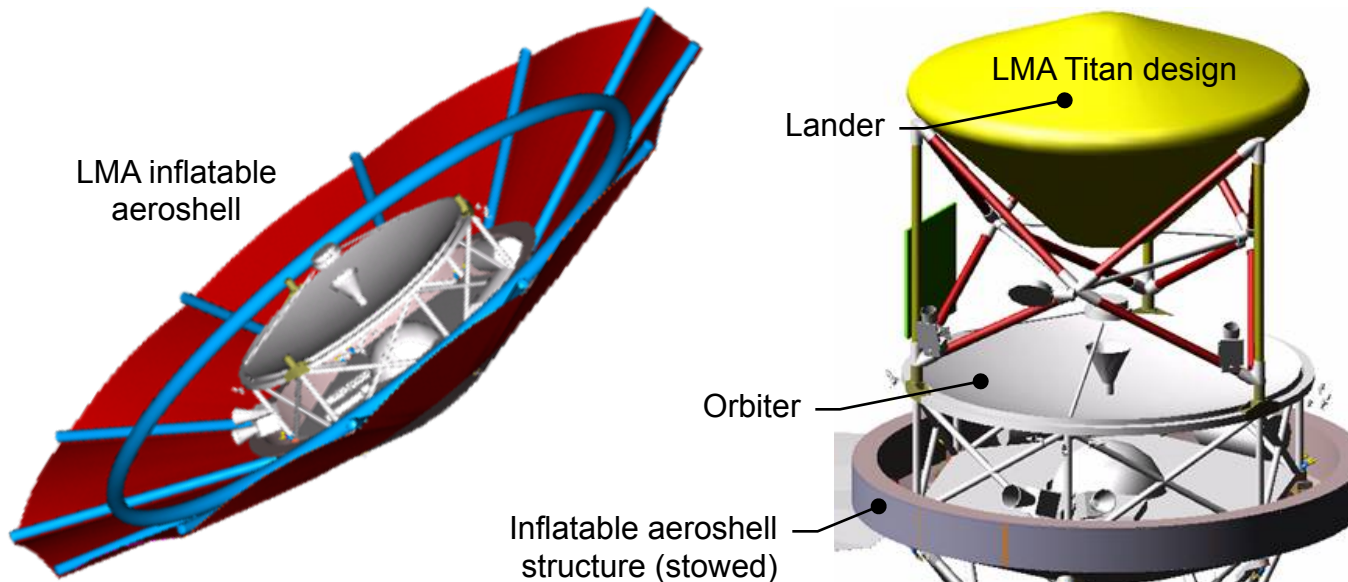
➤ **Summary** – Under Cycle 2, Lockheed Martin Astronautics is under contract to design, fabricate and test an inflatable aeroshell system. This aeroshell design is between an ultralightweight ballute and a rigid aeroshell in terms of size and heat rates/loads.

➤ **Accomplishments:**

- ☐ Established a Titan point of departure (POD) design and mass determination
- ☐ Conducted preliminary trades for each program element
- ☐ Completed initial systems comparisons (rigid vs. inflatable aeroshell)
- ☐ Completed trade studies for alternate shapes and sizes and internal configurations
- ☐ Performed structural analysis to determine strength, stiffness, and stability

➤ **Plans:**

- ☐ Continue systems comparisons (rigid vs. inflatable aeroshell)
- ☐ Construct scaled model for manufacturing process development

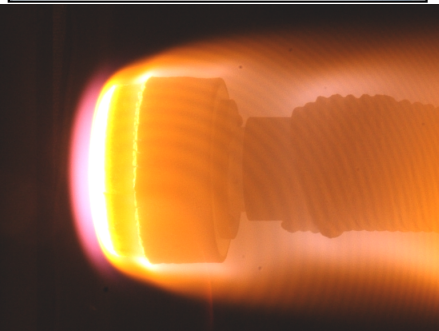


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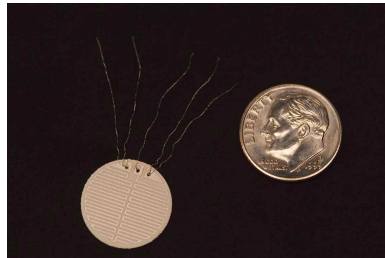
ISPT's Aerocapture Technology Investments Can Increase Efficiency of Planetary Probes/Landers



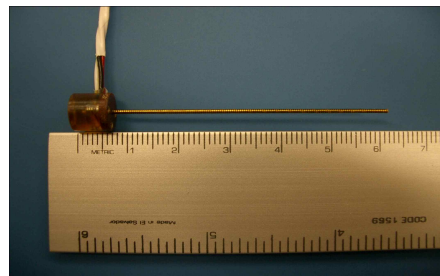
- Ground developments focused on rigid aeroshell hardware and modeling



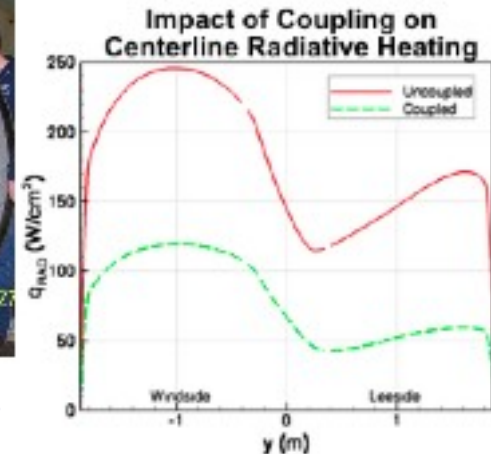
Efficient “family” ablators
provide range of design solutions



Sensors measure the aerothermal
environment to improve predictions
and reduce design margins



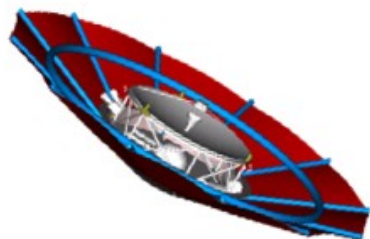
Advanced C-C structures
can improve Genesis
mass by 40% at large scale



State-of-the-art computational
models improve predictions
and quantify risk

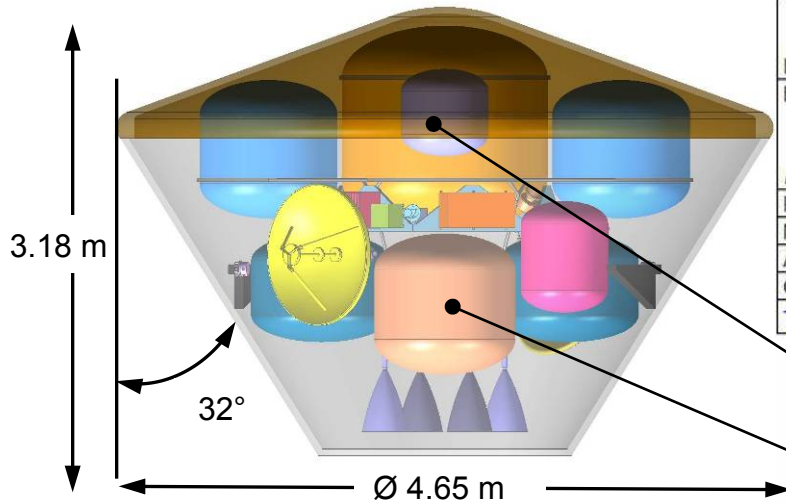
- Modest investments in lower-TRL inflatable decelerator technologies (future investments uncertain in light of current budget outlook)

- Thin films or fabrics are stowed during interplanetary cruise
- Deceleration at high altitudes may enable greater science return during descent



AEROCAPTURE STUDY TASKS:

Mars Aerocapture Systems Study (MASS)

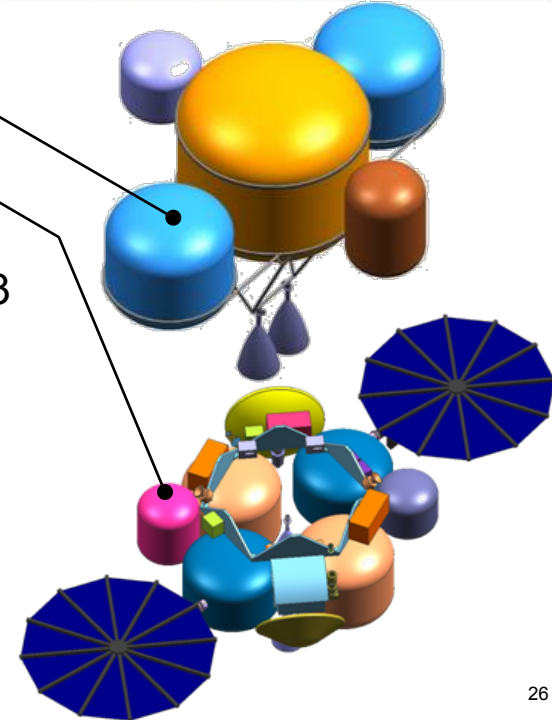


Notional Configuration, Launch Orientation
No primary structure shown

Element	Dry Mass CBE (kg)	Dry Mass w/Contingency (kg)	Propellant Mass (kg)	Total Wet Mass w/Contingency (kg)
Earth Return Vehicle, Total	677	881	2120	3001
ERV, Earth Entry Vehicle		56		
ERV, Jettisoned Sample Capture Hardware		79		
ERV, Bus+Retained Sample Capture Hardware		746		
Propulsion Stage	653	848	2920	3768
Mid-Truss Stage	191	248		248
Aeroshell/Backshell	721			937
Cruise Stage	376	489	255	744
Total Launch Mass				8698
Launch Vehicle C3 (km ² /s ²)				Delta 4050H-19 10.3
Launch Vehicle Capability				7760
Launch Vehicle Margin (kg)				-938
Launch Vehicle Margin (%)				-12.1%
Approximate JPL Design Margin (%)				-1.97%

Propulsion Stage

ERV



- ◆ LaRC-led study, with team from ARC, JPL, JSC, and MSFC
- ◆ The primary objective was to perform a high fidelity aerocapture systems definition study for a large Mars robotic mission (MSR, 2013 Launch)
- ◆ Three stage vehicle: Aeroshell + ERV + Propulsion Stage
 - Fast round trip requires deep space maneuver of over 1 km/s
 - Large propellant load drives mass
- ◆ Challenges: Requires packing density 18% higher than MER (226 kg/m³); negative launch vehicle margin on Delta IV Heavy
- ◆ No major technology gaps uncovered

AEROCAPTURE STUDY TASKS:

Mars Aerocapture Systems Study (MASS)



	2007					2009	
Parameter	Viking	MPF	MPL	MER	Phoenix	MSL (05-22)	MASS
Entry Mass (kg)	980	585	494	832	538	2804	8279
Payload Mass (kg)	600	370	290	421	364	1791	7087
Payload/Entry Mass Fraction	61.2%	63.2%	58.7%	50.6%	67.7%	63.9%	85.6%
Diameter (m)	3.54	2.65	2.4	2.65	2.65	4.5	4.65
Ballistic Coefficient (kg/m ²)	63	63	60	89	64	121	365
Entry Velocity (m/s)	4610	7260	6900	5700	5790	5601	7150
Peak Heat Rate (W/cm ²)	21	106	80	41	47	179	372
Heat Load (J/cm ²)	1100	3865	4322	3687	2827	5013	24,200
Peak Deceleration (Earth g's)	7.24	11	12	6.2		12.7	5.2
L/D	0.18	--	--	--	0.06?	0.24	0.24
G&C	3-Axis	Spin	Spin	Spin	3-Axis	3-Axis	3-Axis
Aeroshell Packing Density (kg/m ³)	140.6	178.3	194	248.5	164	287.3	338.2

- ◆ Advanced aeroshell materials enable mass improvements over current choices

	Total Mass (kg) with Contingency	Savings from Baseline (kg)
Baseline (PICA w/Sandwich)	693	
Carbon-Carbon Hot Structure	526	167
SRAM-20 w/Sandwich	438	255

AEROCAPTURE STUDY TASKS:

Previous System Study Efforts



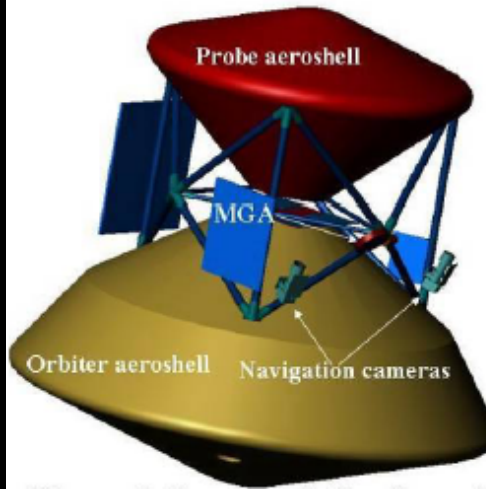
- The In-Space Propulsion Technology (ISPT) Project has commissioned other system studies to develop aerocapture missions to Solar System destinations possessing significant atmospheres:



Systems Analysis for a Venus Aerocapture Mission

NASA TM-2006-214291

URL: <http://hdl.handle.net/2002/16212>



Aerocapture Systems Analysis for a Titan Mission

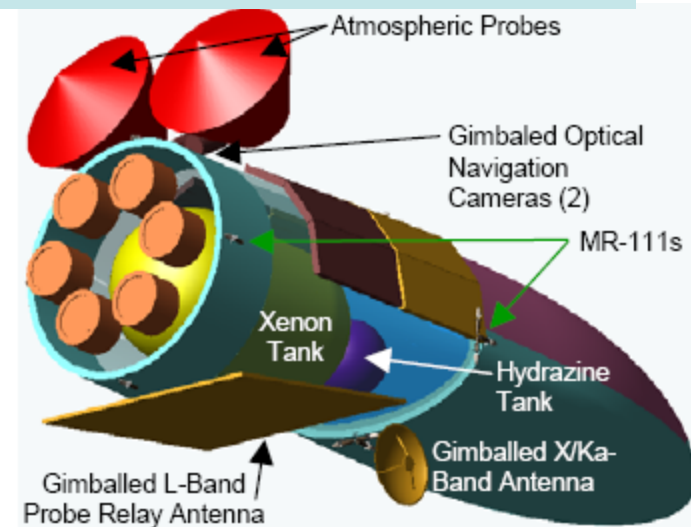
NASA TM-2006-214273

URL: <http://hdl.handle.net/2002/16166>

Aerocapture Systems Analysis for a Neptune Mission

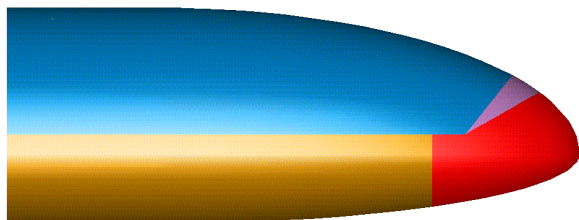
NASA TM-2006-214300

URL: <http://hdl.handle.net/2002/16221>



Aerocapture Study Mission Comparison

	Neptune	Titan	Venus	Large Mars
Entry Velocity (km/sec)	29	6.5	11.25	7.15
Apoapsis/Science Orbit (km)	3986 x 430,000	1700	300	500
Atmos Scale Height at Aerocapture Alt (km)	49	40	4	10.5
L/D	.8	.25	.25	.24
Vehicle Diameter (m)	2.88 (length)	3.75	2.65	4.65
M/CDA (kg/m ²)	895	~90	114	365
Theoretical Corridor (deg)	2.27	3.5	1.55	2.4
Time from Atmos Entry to Atmos Exit (min)	10	42	7.3	6.8
Max g' s During Aerocapture (Earth g' s)	22	3.5	15.3	5.2
Convective Stag Point Heat Rate (W/cm ²)	8000	46	700	370
Radiative Stag Point Heat Rate (W/cm ²)	~4000	75-150	500	~30
Heatshield Materials of Choice	Carbon phenolic, PhenCarb, other	SRAM, SLA	C-C, PhenCarb	SRAM, PhenCarb, C-C



Neptune vehicle concept uses “zoned” TPS approach to minimize mass.

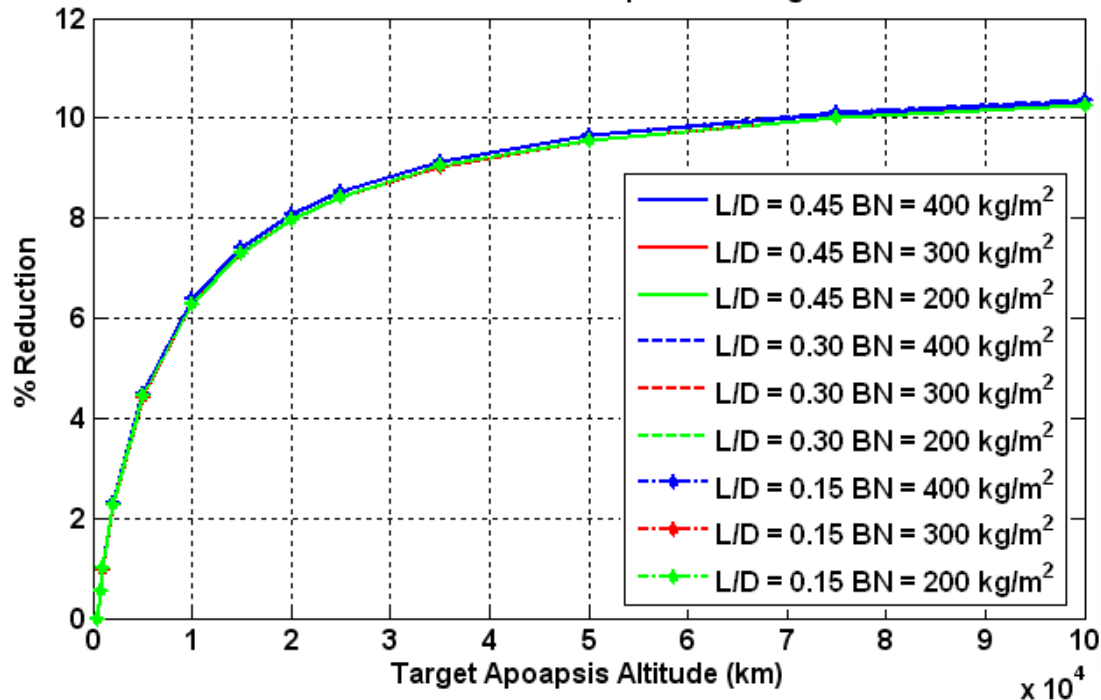
AEROCAPTURE STUDY TASKS:

Multipass Aerocapture

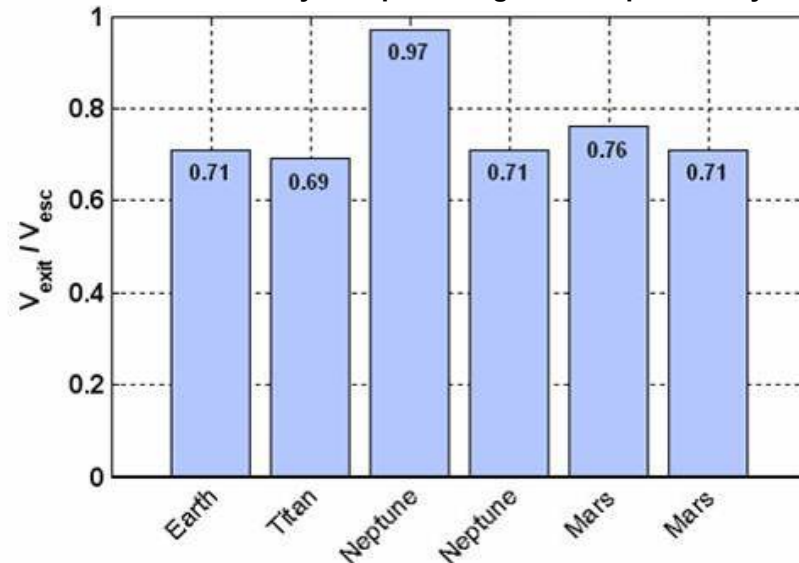


- A Multipass Aerocapture analysis was completed by JSC and LaRC, to identify and document the risks or benefits of performing aerocapture in 2 or more passes. (AIAA paper by Westhelle, et al)
- Results showed that:
 - The maximum heat load on the first pass can be reduced by no more than 23%
 - This reduced heat load enables only a 3% reduction in aeroshell mass.
 - Performing two passes increases the targeting sensitivity and navigation complexity, and adds risk associated with multiple uses of the aeroshell.

Heat Load Reduction Compared to Single Pass



Exit Velocity as a percentage of Escape Velocity



AEROCAPTURE STUDY TASKS:

Aerocapture Probabilistic Risk Assessment

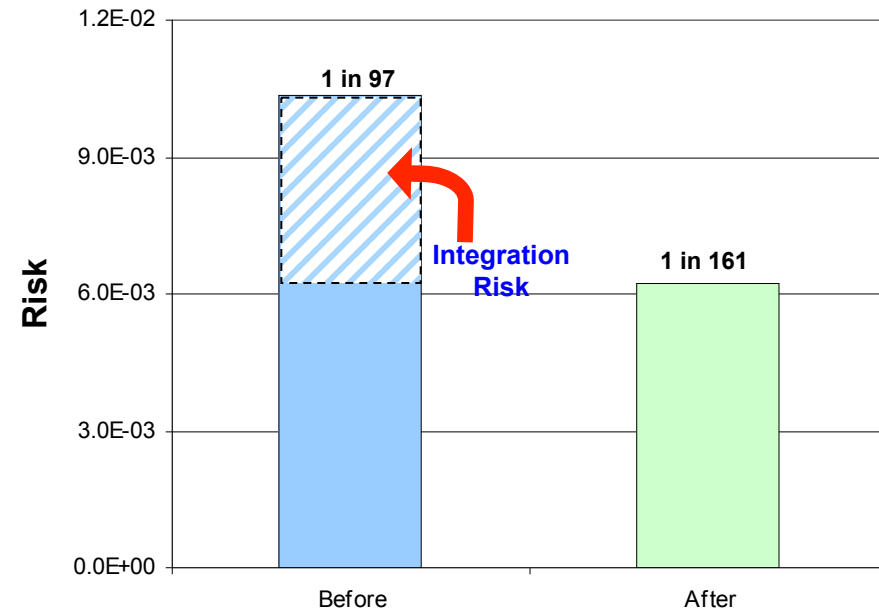


- Initial assessment in February 2005 compared relative risks of capture techniques to quantify current assumptions about the nature of aerocapture
- Study recently modified to quantify benefit of an aerocapture technology validation flight as a risk reducer
- Preview of results:

- **Integration issues tend to surface early in the life of a system**

- Integration risk represents the unknown unknowns that become apparent only after integrating all sub-systems and operating them in a truly relevant environment

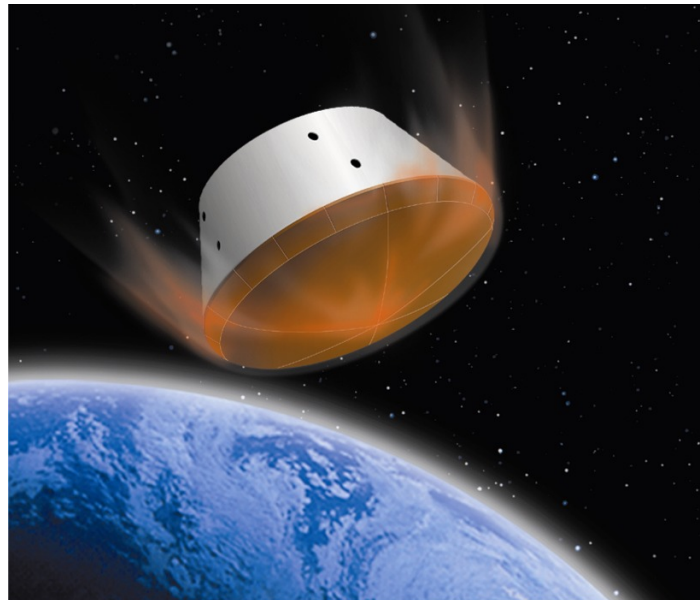
- **The Earth demonstration mission for aerocapture could reduce the risk of the system by 40% based on historical data of like systems**



New Millennium Program's Space Technology 9 Aerocapture Flight Validation Proposal



- The NASA's New Millennium Program is currently sponsoring five competing system technologies for potential flight aboard the Space Technology 9 mission.
- Aerocapture System Technology for Planetary Missions is one of the five competitors.
- If aerocapture is the system technology selected for flight, the ST9 mission will flight validate:
 - Aerocapture as a system technology for immediate use in future missions to Solar System destinations possessing significant atmospheres,
 - New, advanced technologies:
 - Guidance Navigation and Control System
 - Thermal Protection Systems, and
 - Aerothermal and aerodynamic models using a fully instrumented flight aeroshell.



Summary



- The In-Space Propulsion Technology Program has advanced the TRL of Aerocapture over the past 4 years, by funding detailed systems studies, improving and validating modeling capabilities, and advancing more efficient materials, heatshield systems, and sensors for multiple environments.
- Aerocapture is a competitor for a New Millennium spaceflight validation experiment in 2010. The Earth flight of a high-heritage shape will validate the autonomous maneuver execution and a new, more efficient TPS system for future applications.
- Subsystem advancements are now mature enough for proposed missions, such as Discovery, New Frontiers, and Mars Scout, employing entry system technologies (efficient TPS and structures, instruments, GN&C, etc.).

Contact Information



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